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(54) **CHARGING APPARATUS AND ELECTRIC VEHICLE INCLUDING THE SAME**

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(58) **Field of Classification Search**
CPC B60L 11/1814; B60L 11/1811; B60L 11/1812
USPC 320/109
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,795,844 B2 9/2010 Ichikawa
7,891,451 B2 2/2011 Oyobe
8,478,469 B2* 7/2013 Ueo et al. 701/22
8,558,492 B2 10/2013 Oh

(Continued)

FOREIGN PATENT DOCUMENTS

CN 102684283 A 9/2012
GB 1256679 A 12/1971

(Continued)

OTHER PUBLICATIONS

Chinese Office Action dated Jul. 23, 2015, on Chinese Application No. 201410045311.X, 5 pages.

(Continued)

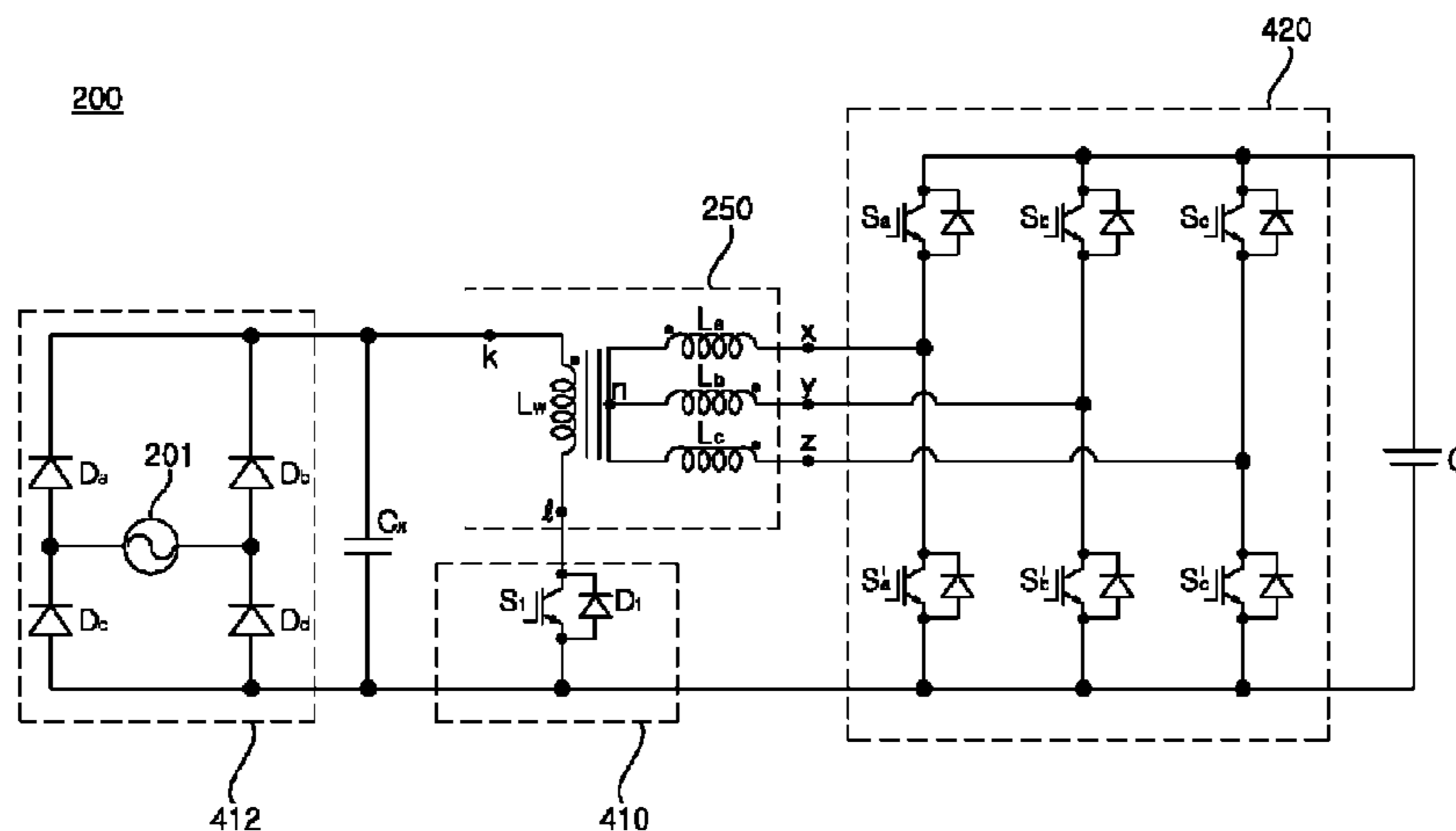
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(57) **ABSTRACT**

A charging apparatus and an electric vehicle including the same are disclosed. The charging apparatus includes a converter for, in a charging mode, converting an input alternating current (AC) voltage into a direct current (DC) voltage and a controller for controlling the converter. The converter includes a motor and a switching unit that is connected to an additional coil wound on a stator of one phase of the motor, and that supplies the input AC voltage to the motor by performing a switching operation. The converter also includes an inverter that, in a motor operation mode, converts a DC voltage from a battery into an AC voltage by a switching operation and drives the motor. In the charging mode, the inverter converts the input AC voltage into the DC voltage using the additional coil of the motor and the switching unit and supplies the DC voltage to the battery.

20 Claims, 7 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

8,736,101 B2 * 5/2014 Masuda et al. 307/10.1
 8,810,060 B2 * 8/2014 Kamaga 307/9.1
 8,872,473 B2 * 10/2014 Song et al. 320/109
 8,901,882 B2 * 12/2014 Song et al. 320/109
 2009/0079389 A1 3/2009 Ohtomo
 2010/0318250 A1 * 12/2010 Mitsutani 701/22
 2011/0279083 A1 11/2011 Asai
 2013/0134909 A1 * 5/2013 Lee 318/139
 2013/0193923 A1 8/2013 Kimura
 2014/0021918 A1 1/2014 Ichikawa
 2014/0217973 A1 8/2014 Lee
 2014/0217974 A1 * 8/2014 Kim et al. 320/109
 2014/0253034 A1 9/2014 Kurimoto
 2015/0175026 A1 6/2015 Uyeki

FOREIGN PATENT DOCUMENTS

JP 2005-130638 A 5/2005
 JP 2007-068362 A 3/2007
 JP 2009-065808 A 3/2009
 KR 10-1999-0074138 A 10/1999
 KR 10-2012-0106457 A 9/2012

OTHER PUBLICATIONS

Korean Notice of Allowance dated Nov. 2, 2015, for Korean Application No. 10-2013-0013516, 4 pages.

* cited by examiner

FIG. 1

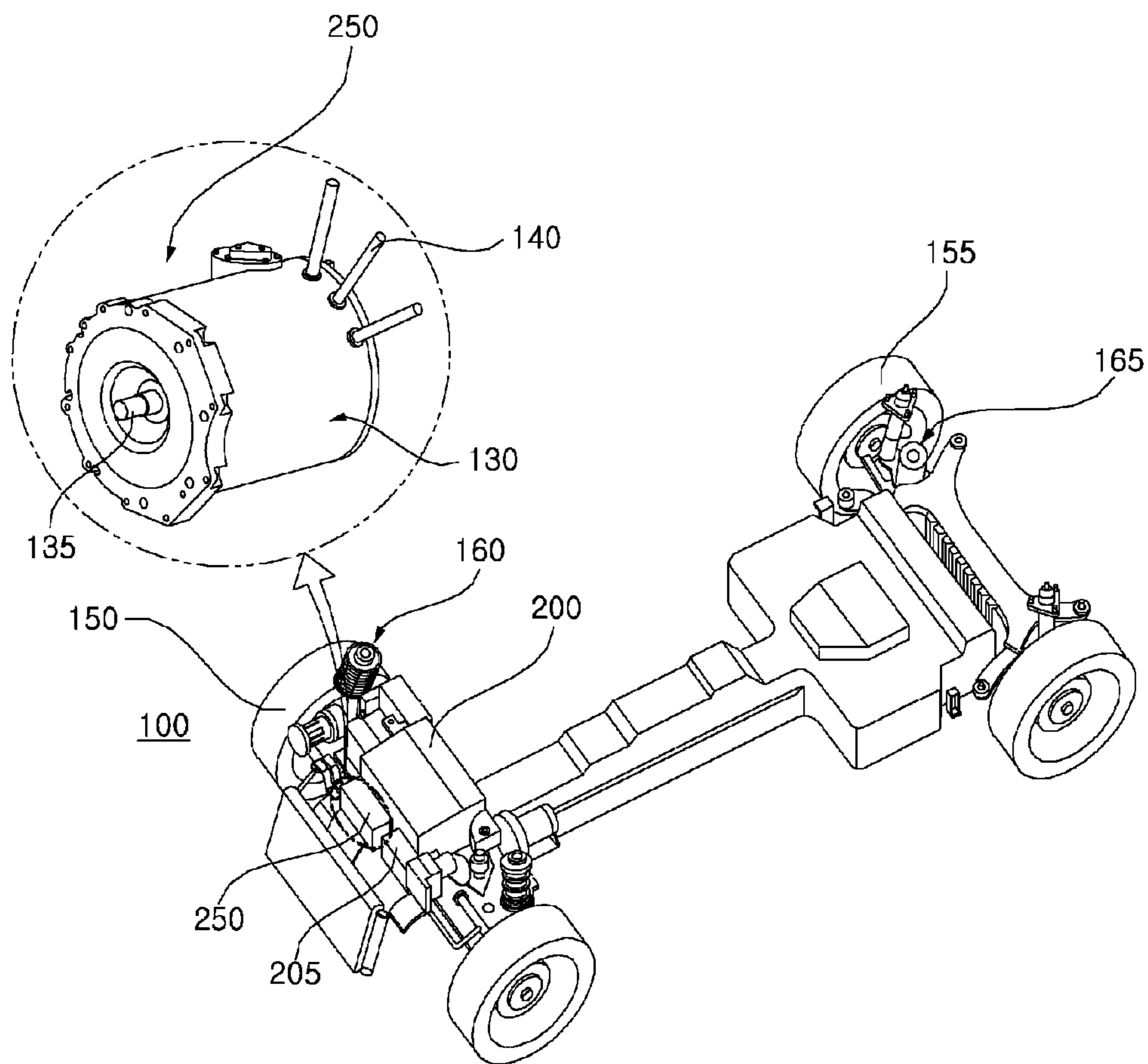


FIG. 2

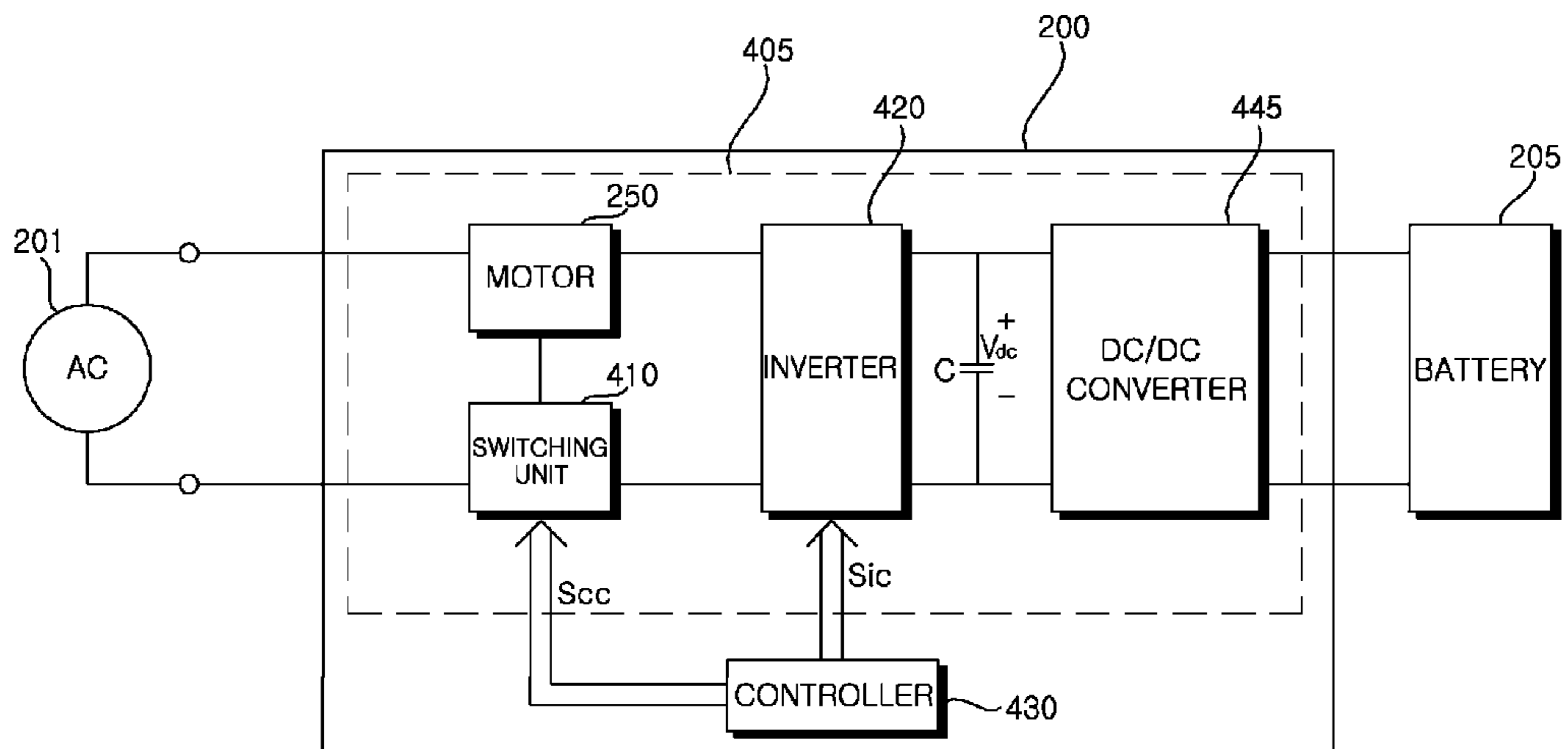


FIG. 3

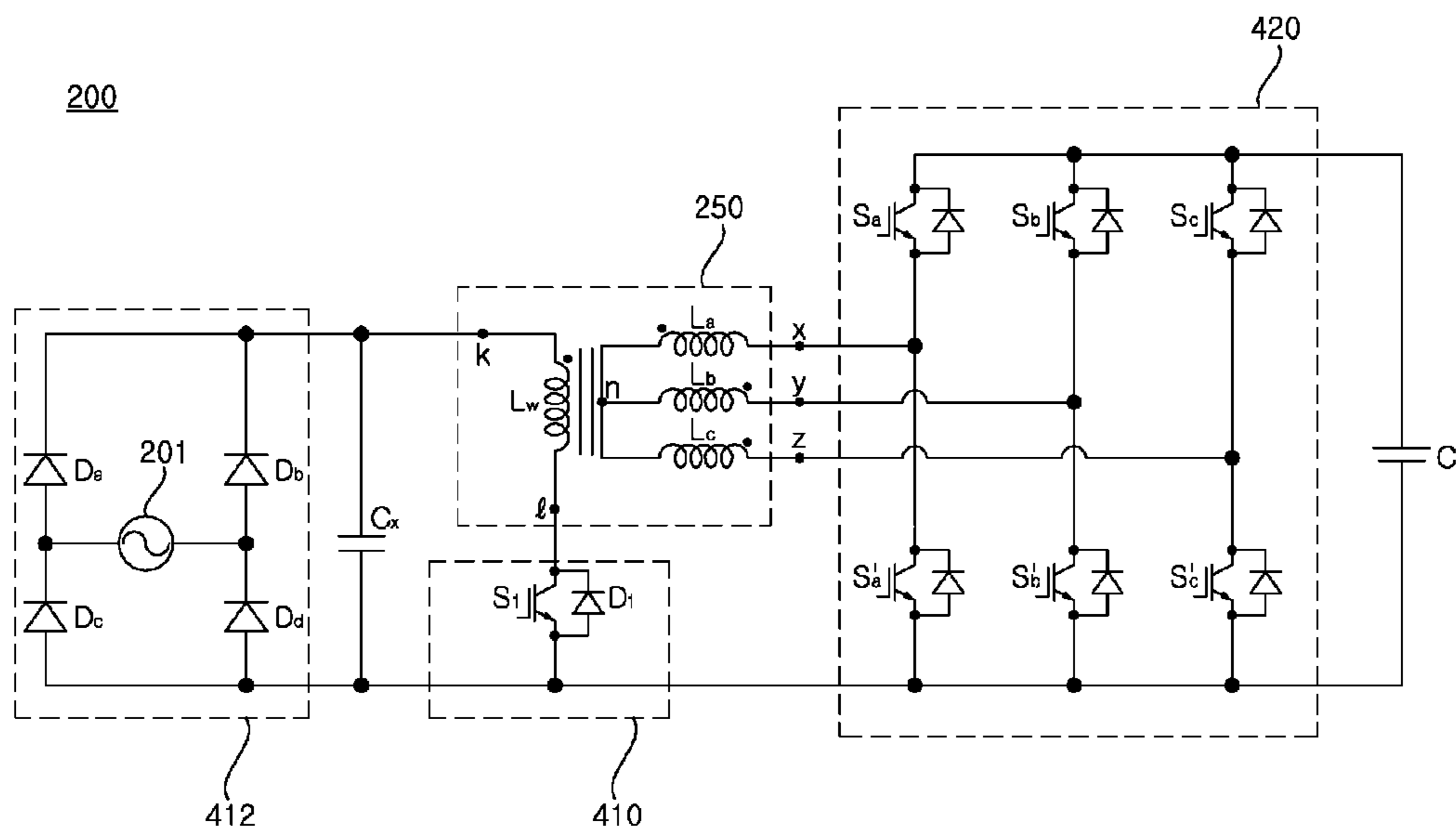


FIG. 4

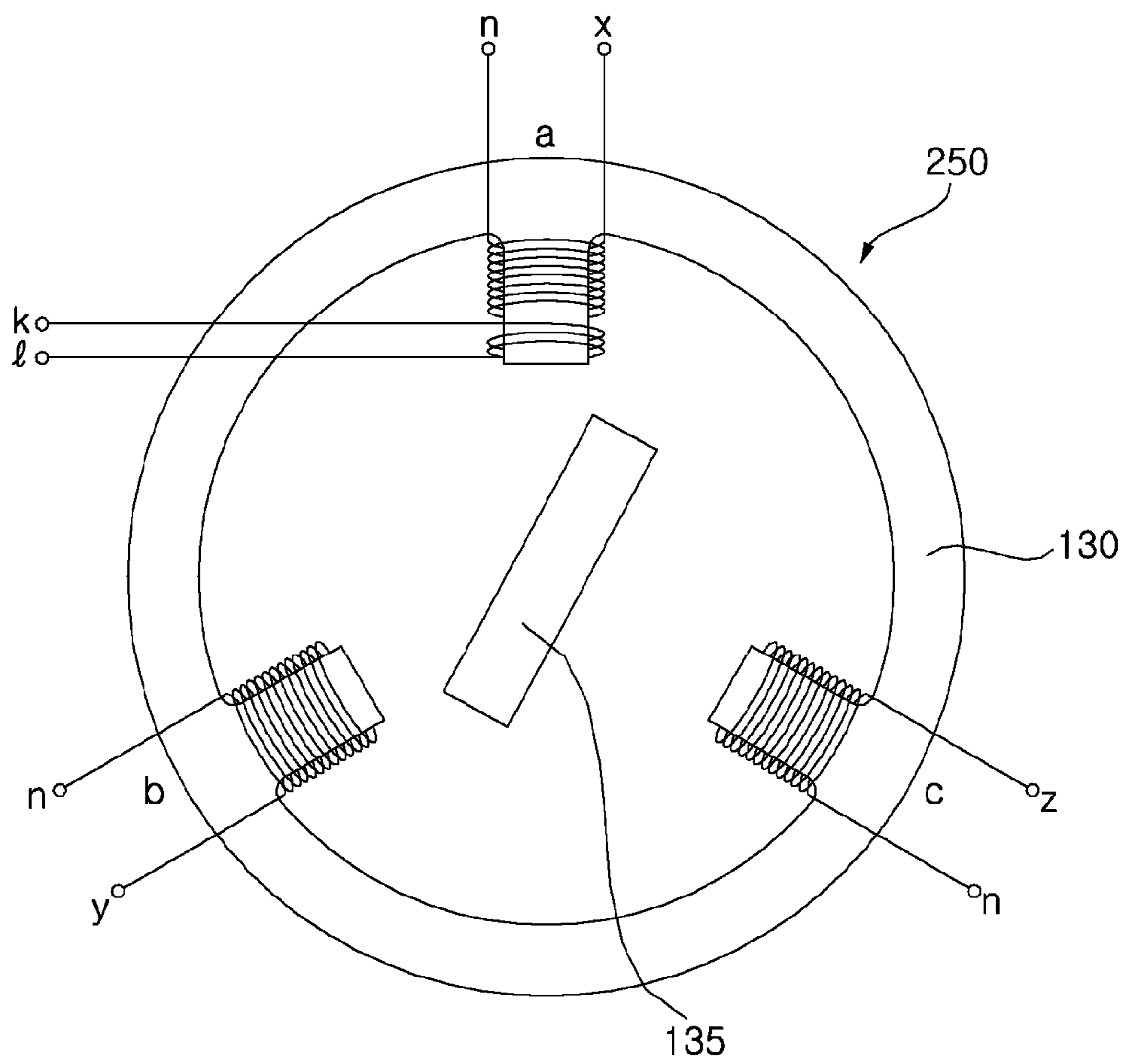


FIG. 5

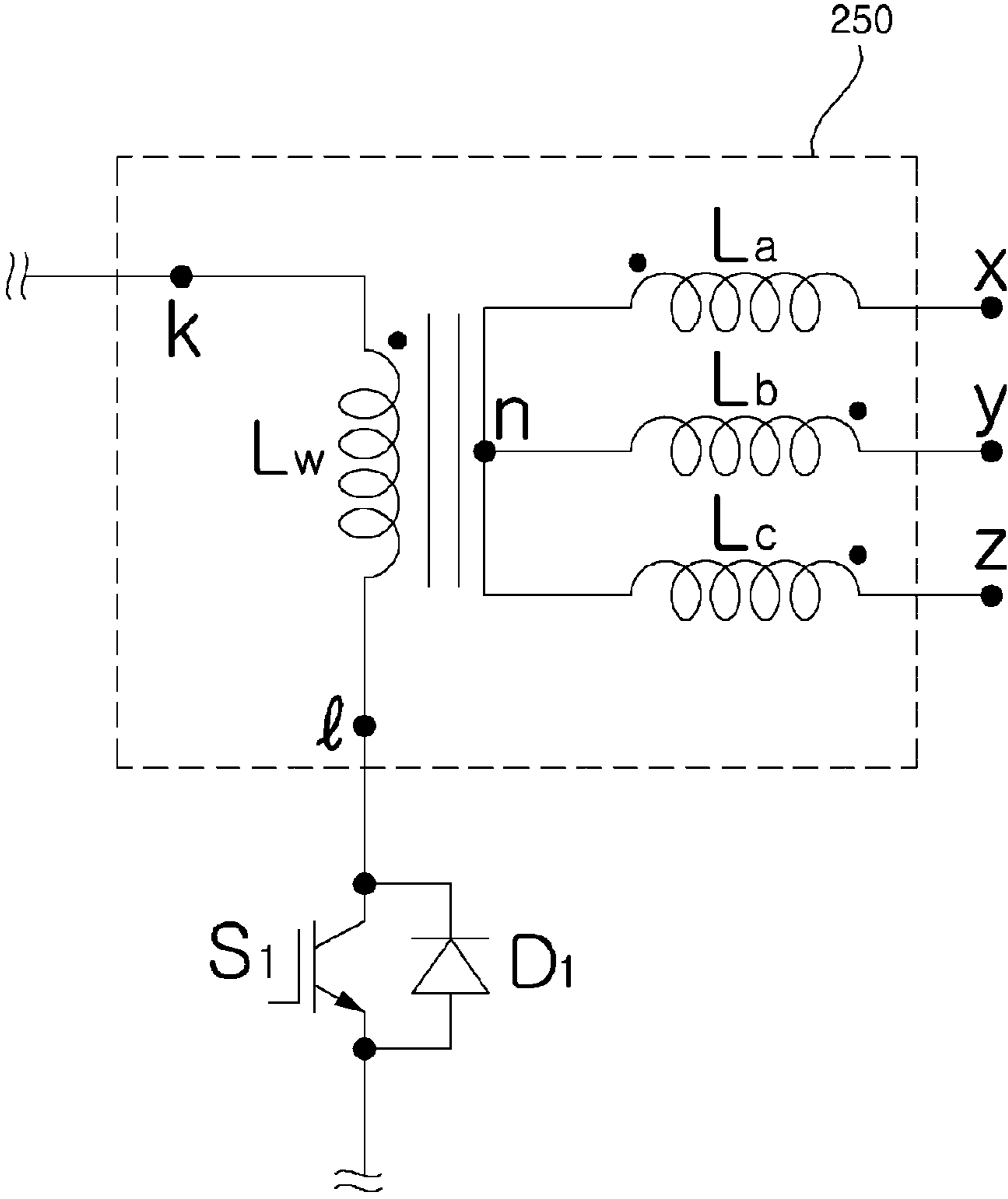


FIG. 6a

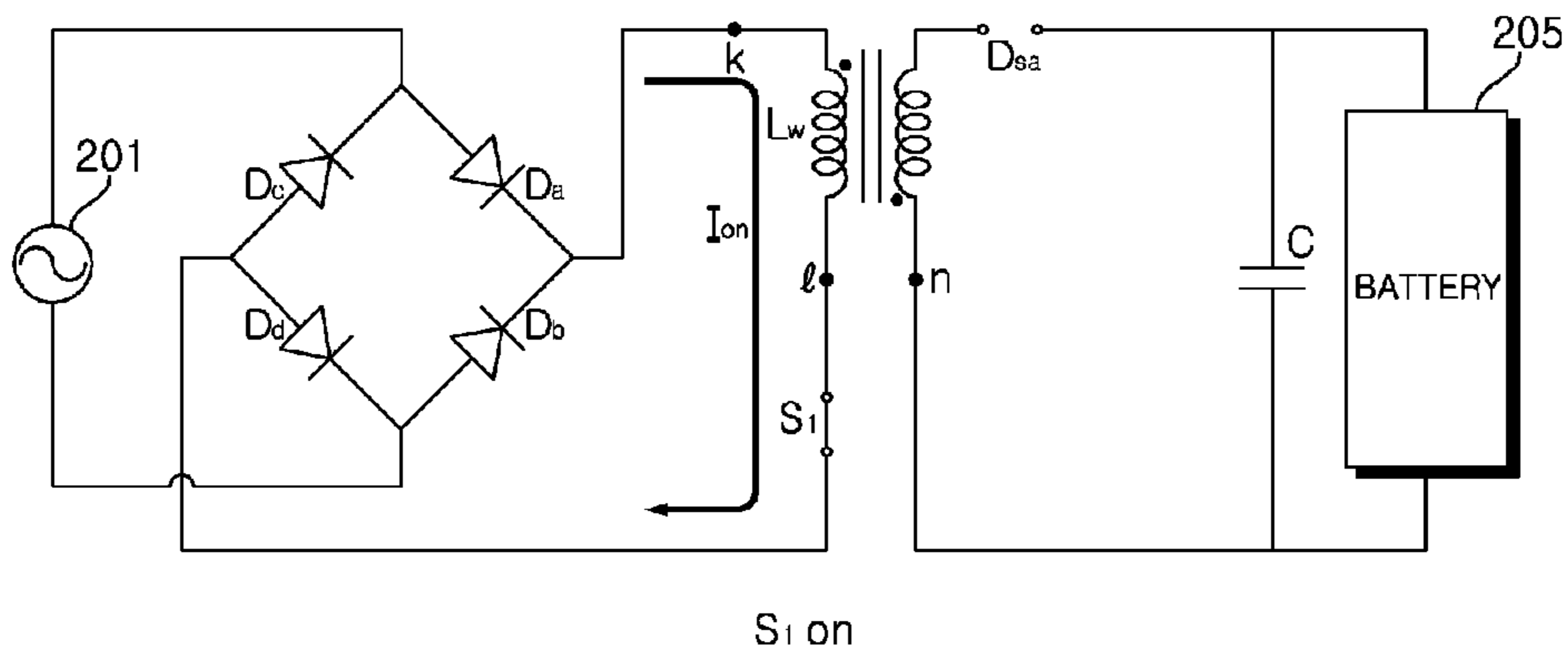


FIG. 6b

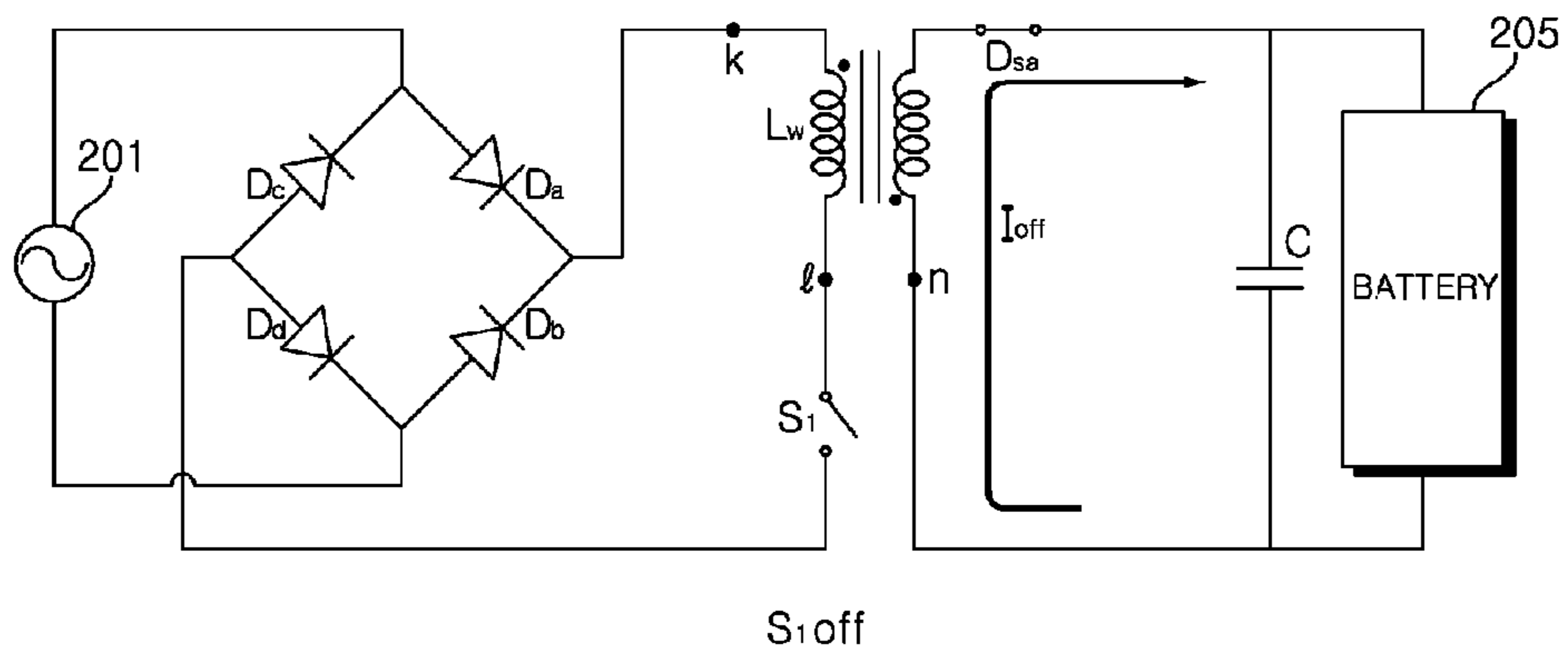
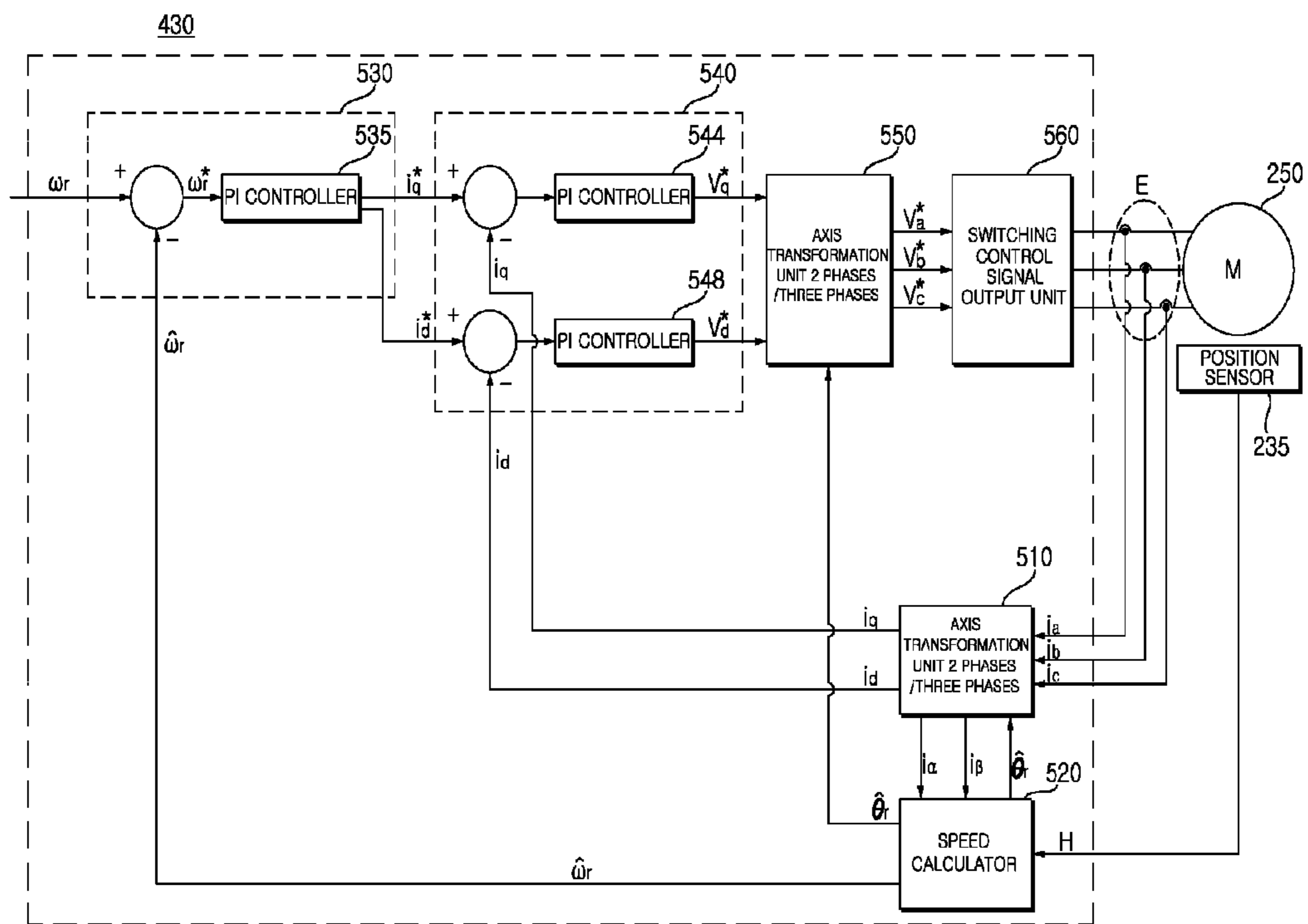


FIG. 7



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CHARGING APPARATUS AND ELECTRIC VEHICLE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Korean Patent Application No. 10-2013-0013516, filed on Feb. 6, 2013, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

FIELD

The present disclosure relates to a charging apparatus and an electric vehicle including the same.

BACKGROUND

A vehicle with an internal combustion engine may lead to environmental pollution or exhaustion of energy due to consumption of energy. Instead of a vehicle using solely an internal combustion engine as a power source, an electric vehicle using electricity as a power source and a hybrid vehicle using an internal combustion engine and electricity have been developed.

Such an electric vehicle or hybrid vehicle generates output using a motor and a battery and various attempts have been made to improve output and mileage.

SUMMARY

In one aspect, a charging apparatus includes a converter configured to, in a charging mode, receive an input alternating current (AC) voltage and convert the input AC voltage into an output direct current (DC) voltage and a controller configured to control the converter. The converter includes a motor that includes a stator and coils wound on the stator with the coils corresponding to different phases of the motor. The converter also includes an additional coil wound on a portion of the stator that corresponds to a phase of the different phases of the motor and a switching unit connected to the additional coil and configured to selectively supply the input AC voltage to the motor by performing a switching operation. The converter further includes an inverter configured to, in a motor operation mode, convert a battery DC voltage from a battery into an output AC voltage by performing a switching operation of three-phase switching elements and drive the motor, and, in the charging mode, convert the input AC voltage into the output DC voltage using the additional coil of the motor and the switching unit and supply the output DC voltage to the battery.

Implementations may include one or more of the following features. For example, in the charging mode, a switching element of the switching unit, the motor, and the inverter may operate as a flyback converter. In addition, energy may be stored in the additional coil by turning a switching element of the switching unit on and the stored energy may be converted into the output DC voltage via the inverter and supplied to the battery by turning the switching element of the switching unit off.

In the charging mode, the additional coil of the motor may operate as a primary side of a transformer and a phase coil wound on the portion of the stator that corresponds to the phase of the different phases of the motor may operate as a secondary side of the transformer. And, the controller may be configured to, in the charging mode, control turning on and off of a switching element of the switching unit. Further, the

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converter may include a rectifier configured to rectify the input AC voltage and supply the rectified voltage to the motor

In some implementations, the inverter, the controller, and the converter may be located on the same circuit board. In these implementations, the controller may be configured to, in the charging mode, turn off all of the three-phase switching elements of the inverter.

In some examples, the controller may include a speed calculator configured to calculate rotator speed information of the motor based on a location signal of the rotator of the motor and a current command generator configured to generate a current command value based on the speed information and a speed command value. In these examples, the controller also may include a voltage command generator configured to generate a voltage command value based on the current command value and detected current flowing in the motor and a switching control signal output unit configured to output a switching control signal that drives the inverter based on the voltage command value.

In some implementations, the controller may be configured to control a duty ratio of turning on the switching unit to perform a voltage boosting operation based on a first voltage across a first capacitor located between the motor and a rectifier of the converter being less than a second voltage across a second capacitor located between the inverter and the battery. In these implementations, the controller may be configured to control the duty ratio of turning on the switching unit to perform a voltage drop operation based on the first voltage across the first capacitor being greater than the second voltage across the second capacitor.

In another aspect, an electric vehicle includes a battery and a charging apparatus including a converter configured to, in a charging mode, receive an input alternating current (AC) voltage and convert the input AC voltage into an output direct current (DC) voltage and a controller configured to control the converter. The converter includes a motor that includes a stator and coils wound on the stator with the coils corresponding to different phases of the motor. The converter also includes an additional coil wound on a portion of the stator that corresponds to a phase of the different phases of the motor and a switching unit connected to the additional coil and configured to selectively supply the input AC voltage to the motor by performing a switching operation. The converter further includes an inverter configured to, in a motor operation mode, convert a battery DC voltage from a battery into an output AC voltage by performing a switching operation of three-phase switching elements and drive the motor, and, in the charging mode, convert the input AC voltage into the output DC voltage using the additional coil of the motor and the switching unit and supply the output DC voltage to the battery.

Implementations may include one or more of the following features. For example, in the charging mode, a switching element of the switching unit, the motor, and the inverter may operate as a flyback converter. In addition, the charging apparatus may store energy in the additional coil by turning a switching element of the switching unit on, and may convert the stored energy into the output DC voltage via the inverter and supply the converted DC voltage to the battery by turning the switching element of the switching unit off.

In the charging mode, the additional coil of the motor may operate as a primary side of a transformer and a phase coil wound on the portion of the stator that corresponds to the phase of the different phases of the motor may operate as a secondary side of the transformer. And, the controller may be configured to, in the charging mode, turn on and off all of the three-phase switching elements of the switching unit. Further,

the converter may include a rectifier configured to rectify the input AC voltage and supply the rectified voltage to the motor.

In some implementations, the inverter, the controller, and the switching unit may be located on the same circuit board. In these implementations, the controller may be configured to, in the charging mode, turn off all of the three-phase switching elements of the inverter.

In some examples, the controller may include a speed calculator configured to calculate rotator speed information of the motor based on a location signal of the rotator of the motor and a current command generator configured to generate a current command value based on the speed information and a speed command value. In these examples, the controller may include a voltage command generator configured to generate a voltage command value based on the current command value and detected current flowing in the motor and a switching control signal output unit configured to output a switching control signal that drives the inverter based on the voltage command value.

In some implementations, the controller may be configured to control a duty ratio of turning on the switching unit to perform a voltage boosting operation based on a first voltage across a first capacitor located between the motor and a rectifier of the converter being less than a second voltage across a second capacitor located between the inverter and the battery. In these implementations, the controller may be configured to control the duty ratio of turning on the switching unit to perform a voltage drop operation based on the first voltage across the first capacitor being greater than the second voltage across the second capacitor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing an example of the body of an example electric vehicle;

FIG. 2 is a block diagram showing an example of the internal configuration of a driving unit of FIG. 1;

FIG. 3 is a circuit diagram of an example of the driving unit of FIG. 2;

FIG. 4 is a diagram showing an example of the structure of a motor of FIG. 2;

FIG. 5 is a diagram showing an example of an equivalent circuit of a motor of FIG. 4;

FIGS. 6a and 6b are views referred to for describing example operation of the circuit of FIG. 3; and

FIG. 7 is a block diagram showing an example of the internal configuration of a controller of FIG. 2.

DETAILED DESCRIPTION

FIG. 1 illustrates an example body of an example electric vehicle.

Referring to FIG. 1, the electric vehicle 100 may include a battery 205 for supplying a voltage, and a motor driving unit 200 for receiving a voltage from the battery 205 and driving a motor 250. The motor 250 is rotated by the motor driving unit 200. Front wheels 150 and rear wheels 155 are rotated by the motor 250, and front-wheel and rear-wheel suspensions 160 and 165 reduce (e.g., prevent) vibrations of the road from being delivered to the vehicle body. The electric vehicle may further include a driving gear for changing the rotation speed of the motor 250 according to a gear ratio.

The battery 205 supplies a voltage to the motor driving unit 200. In particular, the battery supplies a direct current (DC) voltage to a capacitor C of the motor driving unit 200.

The battery 205 may be formed of a set of a plurality of unit cells. The plurality of unit cells may be managed by a battery

management system (BMS) in order to maintain a constant voltage. That is, the plurality of unit cells may output a constant voltage by the BMS.

For example, the BMS may detect a voltage V_{bat} of the battery 205 and send the voltage V_{bat} to an electronic controller, such as a controller 430 (see FIG. 2) of the motor driving unit 200. If the voltage V_{bat} of the battery is decreased to a lower limit value or less, the BMS may supply the DC voltage stored in the capacitor C of the motor driving unit 200 to the battery. In addition, if the voltage V_{bat} of the battery is increased to an upper limit value or more, the BMS may supply a DC voltage to the capacitor C of the motor driving unit 200.

The battery 205 may be composed of a secondary battery for charging or discharging. Other arrangements also are possible.

The motor driving unit 200 receives a DC voltage from the battery 205 via a power input cable in a motor operation mode. The motor driving unit 200 converts the DC voltage received from the battery 205 into an alternating current (AC) voltage and supplies the AC voltage to the motor 250. The converted AC voltage may be a three-phase AC voltage.

The motor driving unit 200 supplies the three-phase AC voltage to the motor 250 via a three-phase output cable included in the motor driving unit 200 in the motor operation mode. Although the motor driving unit 200 may have a three-phase output cable composed of three cables, three cables may be included in a single cable.

The motor driving unit 200 may receive an input AC voltage, convert the input AC voltage into a DC voltage, and supply the DC voltage to the battery 205, in a charging mode. Thus, the motor driving unit 200 may be referred to as a charging apparatus.

In the present specification, the motor driving unit 200 and the charging apparatus are used interchangeably and have the same meaning.

The motor 250 includes a stator 130 and a rotator 135. The motor 250 includes an input cable 140 and receives an AC voltage from the motor driving unit 200. The motor 250 may be a three-phase motor, for example. If a variable voltage/variable frequency AC voltage of each phase is applied to a coil of the stator of each phase, the rotation speed of the rotator is changed according to applied frequency.

The motor 250 may include various motors such as an induction motor, a brushless DC motor (BLDC), a reluctance motor, etc.

The driving gear may be provided on one side of the motor 250. The driving gear converts rotation energy of the motor 250 according to gear ratio. The rotation energy output from the driving gear is delivered to the front wheels 150 and/or the rear wheels 155 to move the electric vehicle 100.

The front-wheel suspension 160 and the rear-wheel suspension 165 support the front wheels 150 and the rear wheels 155, respectively. The front-wheel suspension 160 and the rear-wheel suspension 165 support the wheels by a spring or a damper in a vertical direction such that vibrations of the road do not reach the vehicle body.

The front wheels 150 may include a steering apparatus. The steering apparatus steers the front wheels 150 such that a driver steers the electric vehicle 100 in a desired direction.

In some implementations, the electric vehicle 100 may include an electronic controller for controlling electronic apparatuses included in the electric vehicle. The electronic controller controls operation and display of each apparatus. In addition, the electronic controller may control the BMS.

The electronic controller may generate a driving command value according to various driving modes (forward mode,

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backward mode, neutral mode and parking mode), based on sensed signals from an inclination angle sensor for sensing an inclination angle of the electric vehicle **100**, a speed sensor for sensing the speed of the electric vehicle **100**, a brake sensor for sensing operation of a brake pedal and an accelerator sensor for sensing operation of an accelerator pedal. The driving command value may be a torque command value or a speed command value, for example.

The electric vehicle **100** may include an electric vehicle using a battery and a motor and a hybrid electric vehicle using a battery and a motor while using an engine. The hybrid electric vehicle may further include a switch for selecting any one of the battery and the engine and a transmission. A method for driving the hybrid electric vehicle may be divided into a serial method for converting mechanical energy output from the engine into electric energy to drive the motor and a parallel method for simultaneously utilizing mechanical energy output from the engine and electric energy of the battery.

The motor driving unit **200** will be described below with reference to FIG. **2** and subsequent figures thereof.

FIG. **2** shows an example of the internal configuration of the driving unit of FIG. **1**, and FIG. **3** illustrates example circuitry of the driving unit of FIG. **2**.

The motor driving unit **200**, that is, the charging apparatus **200**, may include a converter **405** and a controller **430**. The converter **405** may include a switching unit **410**, a motor **250**, an inverter **420** and a DC/DC converter **445**. Here, the DC/DC converter **445** may be selectively included.

The switching unit **410** is provided at a front stage of the motor **250** and includes a switching element S_1 to supply a voltage from an input AC power source **201** to the motor **250** by a switching operation of the switching element.

Although the input AC power source **201** is a single-phase AC power source in FIG. **2**, the input AC power source may be a three-phase AC power source.

A rectifier (**412** of FIG. **3**) for rectifying the voltage from the input AC power source **201** may be further provided at a front stage of the switching unit **410**.

In FIG. **3**, as the rectifier **412** of the single-phase AC voltage, four diodes D_a , D_b , D_c and D_d are used in the form of a bridge.

The switching unit **410** may additionally be connected to an additional coil wound on a stator of any one phase of the motor **250**. A capacitor C_x for smoothing the rectified voltage may be further provided between the motor **250** and the rectifier **412**, that is, between the switching unit **410** and the rectifier **412**.

FIG. **3** shows an example of an equivalent circuit of the motor **250**. The three-phase motor **250** may be electrically expressed by an a-phase inductor L_a , a b-phase inductor L_b and a c-phase inductor L_c .

The switching unit **410** may operate as a flyback converter, along with the motor **250** and, more particularly, the additional coil of the motor.

In FIG. **3**, as the rectifier **412** of the single-phase AC voltage, four diodes D_a , D_b , D_c and D_d are used in the form of a bridge.

The switching element S_1 is electrically connected between the rectifier **412** and the motor **250** and, more particularly, between the rectifier **412** and the additional coil wound on the stator of any one phase of the motor **250**, thereby performing a switching operation.

In the charging mode, by turning the switching element S_1 on, the voltage from the rectifier **412** is delivered to the additional coil of the motor **250** such that energy is stored in

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the additional coil. At this time, all the switching elements of the inverter **420** are turned off.

In the charging mode, by turning the switching element S_1 off, the voltage from the rectifier **412** is no longer delivered to the additional coil of the motor **250** but the energy stored in the additional coil may be delivered to the battery **205** via the inverter **420**. At this time, all the switching elements of the inverter **420** are turned off, but the diodes may be conducted in one direction, and the diodes in the inverter **420** may supply the current to the battery.

By the turn-on/off operation of the switching element S_1 , the input AC voltage is converted into DC voltage.

Although a general flyback converter includes an inductor, the switching unit **410** does not include an inductor and uses the phase coil and the additional coil wound on the stator **130** of the motor **250** as the inductor.

The switching element S_1 of the switching unit **410** may be controlled by a switching control signal S_{cc} of the controller **430**.

An input current detector may be provided between the rectifier **412** and the input AC power source **201**. In addition, an input voltage detector may be provided across a capacitor C_x of the switching unit **410**.

The input current detector may detect input AC current received from the input AC power source **201**. As the input current detector, a current transformer (CT), a shunt resistor, etc. may be used. The detected input AC current may be input to the controller **430** as a discrete signal having a pulse shape.

The input voltage detector may detect a voltage across the capacitor C_x . The input voltage detector may include a resistor, an amplifier, etc. The detected input voltage may be input to the controller **430** as a discrete signal having a pulse shape.

The inverter **420** includes a plurality of inverter switching elements, which may convert a DC voltage V_{dc} smoothed by an on/off operation of the switching elements into three-phase AC voltages v_a , v_b and v_c having a predetermined frequency and output the three-phase AC voltages to the three-phase synchronization motor **250**.

In the inverter **420**, upper-arm switching elements S_a , S_b and S_c and lower-arm switching elements S'_a , S'_b and S'_c , connected in series form respective pairs and a total of three pairs of upper-arm and lower-arm switching elements S_a & S'_a , S_b & S'_b and S_c & S'_c are connected in parallel. The switching elements S_a , S'_a , S_b , S'_b , S_c and S'_c , are connected with diodes in inverse parallel.

The switching elements of the inverter **420** perform the on/off operation based on an inverter switching control signal S_{ic} from the controller **430**.

The inverter **420** converts the DC voltage from the battery to the AC voltage and drives the motor **250** in the operation mode of the motor **250**.

In the inverter **420**, all the three-phase switching elements S_a , S'_a , S_b , S'_b , S_c and S'_c of the inverter **420** are turned off in the charging mode.

The switching element S_1 of the switching unit **410** is turned on such that the a-phase upper-arm diode D_{sa} connected to the a-phase upper-arm switching element in inverse parallel is turned off, and the switching element S_1 of the switching unit **410** is turned off such that the a-phase upper-arm diode D_{sa} connected to the a-phase upper-arm switching element in inverse parallel is turned on.

Therefore, in the charging mode, the voltage from the input AC power source **201** may be converted into the DC voltage through the switching unit **410**, the motor **250** and the switching element of one phase of the inverter **420**, that is, the diode connected to the switching element of one phase in inverse

parallel, and may be supplied to the battery **205**, which will be described in more detail below with reference to FIG. **4**.

The controller **430** may control the operation of the switching elements of the inverter **420**. The controller **430** may receive output current detected by the output current detector **E** of FIG. **7**.

The controller **430** outputs the inverter switching control signal S_{ic} to the inverter **420** in order to control the switching operation of the inverter **420**. The inverter switching control signal S_{ic} is a pulse width modulation (PWM) switching control signal and is generated and output based on the output current value detected by the output current detector **E**.

The controller **430** may control the switching operation of the switching element S_1 of the switching unit **410** in the charging mode. The controller **430** may receive input current detected by the input current detector. The controller **430** may output the converter switching control signal S_{cc} to the switching unit **410** in order to control the switching operation of the switching unit **410**. The converter switching control signal S_{cc} is a pulse width modulation (PWM) switching control signal and is generated and output based on the input current detected by the input current detector.

The output current detector (**E** of FIG. **7**) may detect output current flowing between the inverter **420** and the three-phase motor **250**, that is, current flowing in the motor **250**. The output current detector **E** may detect output currents i_a , i_b and i_c of respective phases or detect output currents of two phases using ternary phase equilibrium.

The output current detector **E** may be provided between the inverter **420** and the motor **250**. For current detection, a current transformer (CT), a shunt resistor, etc. may be used.

If shunt resistors are used, three shunt resistors may be provided between the inverter **420** and the synchronization motor **250** or one end of each of the three shunt resistors may be connected to each of the three lower-arm switching elements, S'_a , S'_b and S'_c of the inverter **420**. Alternatively, two shunt resistors may be used using ternary phase equilibrium. If one shunt resistor is used, the shunt resistor may be provided between the capacitor **C** and the inverter **420**.

The detected output current is a discrete signal having a pulse shape and may be applied to the controller **430**. Based on the detected output current, the inverter switching control signal S_{ic} is generated. Hereinafter, assume that the detected output current is three-phase output currents i_a , i_b and i_c .

The DC/DC converter **445** may be a bi-directional converter. That is, in the motor driving mode, the level of the DC voltage stored in the battery **205** is changed and the level-changed DC voltage is output to the inverter **420**. In the charging mode, the level of the generated DC voltage may be changed and the level-changed DC voltage may be sent to the battery **205** by the switching operation of the inverter **420**.

The DC/DC converter **445** may not be included in the driving unit **200**.

The capacitor **C** for storing the DC voltage may be provided between the inverter **420** and the battery **205**. The capacitor **C** may serve as a smoothing capacitor and the smoothing capacitor **C** may smooth the input voltage and store the smoothed voltage.

Although one smoothing capacitor **C** is shown in the figure, a plurality of capacitors may be included for stability.

In FIG. **3**, the capacitor **C** is provided between the inverter **420** and the DC/DC converter **445**.

Both ends of the capacitor **C** may be referred to as DC ends or DC link ends, because a DC voltage is stored.

The driving unit **200** may further include a DC end voltage detector for detecting the voltage between both ends of the capacitor **C**.

The DC end voltage detector may detect a DC end voltage V_{dc} between both ends of the smoothing capacitor **C**. The DC end voltage detector may include a resistor, an amplifier, etc. The detected DC end voltage V_{dc} may be a discrete signal having a pulse shape and may be input to the controller **430**.

If the DC/DC converter **445** is not provided between the inverter **420** and the battery **205**, the DC end voltage V_{dc} detected by the DC end voltage detector may correspond to the voltage V_{BAT} of the battery **205**.

The controller **430** may determine voltage boosting or voltage drop in the charging mode using the DC end voltage V_{dc} and the input voltage corresponding to the voltage V_{BAT} of the battery **205**.

The switching unit **410**, the inverter **420** and the controller **430** are included in the driving unit **200**, that is, the charging apparatus **200**, and may be located on the same circuit board. Such a charging apparatus may be referred to as an on board charger (OBC). The inverter, the controller and the switching unit of the charging apparatus are provided on the same circuit board, thereby implementing a small-size charging apparatus.

In addition to the switching unit **410**, the inverter **420**, and the controller **430**, the DC/DC converter **445** may be included in the driving unit **200**, that is, the charging apparatus **200**, and may be located on the same circuit board.

FIG. **4** shows an example of the structure of the motor of FIG. **2** and FIG. **5** shows an example of an equivalent circuit of the motor of FIG. **4**.

Referring to FIG. **4**, the motor **250** is a three-phase AC motor and includes a stator **130** of an a-phase, a b-phase and a c-phase and a rotator **135**.

In the motor operation mode, PWM signals are input to coils wound on the stator **130** of the a-phase, the b-phase and the c-phase. Thus, the rotator **135** rotates by an electric field and a magnetic field.

In the motor **250**, an additional coil may be wound on any one of the a-phase, the b-phase and the c-phase, for example, the a-phase stator, in addition to the phase coils.

In the figure, the a-phase coil is wound on the a-phase stator between a node x and a node n , the b-phase coil is wound on the b-phase stator between a node y and the node n , and the c-phase coil is wound on the c-phase stator between a node z and the node n . Here, the node n denotes a common neutral point of the a-phase, the b-phase and the c-phase.

In the figure, the additional coil is separated from the a-phase coil and is wound on the a-phase stator between a node k and a node l .

In addition to the phase coils, the additional coil may be used. That is, the additional coil is used as a primary side of a transformer of the flyback converter and the phase coil is used as a secondary side of the transformer.

The motor **250** may be expressed by the equivalent circuit shown in FIG. **5**.

That is, between the node k and the node l , an inductor L_w of the additional coil is used as the primary side of the transformer of the flyback converter and the switching element S_1 of the switching unit **410** may be connected to the node l .

Between the node x and the node n , between the node y and the node n and between the node z and the node n , the a-phase inductor L_a , the b-phase inductor L_b and the c-phase inductor L_c may be connected in parallel. Any one of the a-phase inductor L_a , the b-phase inductor L_b and the c-phase inductor L_c , for example, the a-phase inductor L_a , is used as the secondary side of the transformer.

In the charging mode, all the switching elements S_a , S'_a , S_b , S'_b , S_c and S'_c of the inverter **420** may be turned off. Thus, the

controller **430** may control turn-off of all the switching elements S_a , S'_a , S_b , S'_b , S_c and S'_c in the charging mode.

In the charging mode, since all the switching elements of the inverter are turned off, the rotator of the motor does not rotate.

The equivalent circuit of FIG. **5** may be referred to as a flyback converter, because the switching element S_1 , the inductor L_w of the additional coil, the a-phase inductor L_a , the b-phase inductor L_b and the c-phase inductor L_c operate in the flyback mode.

FIGS. **6a** and **6b** illustrate example operation of the circuit of FIG. **3**.

First, FIG. **6a** shows the case in which the equivalent circuit of the driving unit **200** of FIG. **5** operates in an energy accumulation mode of the charging mode as a flyback converter.

FIG. **6a** shows the case in which, if the switching element S_1 is turned on, a closed loop is formed by the inductor L_w of the additional coil and the switching element S_1 such that current I_{on} flows. Accordingly, energy is accumulated in the inductor L_w of the additional coil, that is, the primary side of the transformer, based on current I_{on} . At this time, the a-phase upper-arm switching element S_a is turned off.

In the energy accumulation mode, induced current generated at the secondary side of the transformer does not flow due to the diode D_{sa} connected to the a-phase upper-arm switching element S_a .

Next, FIG. **6b** shows the case in which the equivalent circuit of the driving unit **200** of FIG. **5** operates in an energy open mode of the charging mode as a flyback converter.

FIG. **6b** shows the case in which, if the switching element S_1 is turned off, current I_{off} induced from energy stored in the inductor L_w of the additional coil flows through the a-phase inductor L_a and the diode D_{sa} connected to the a-phase upper-arm switching element S_a in inverse parallel. That is, a closed loop is formed by the a-phase inductor L_a and the diode D_{sa} such that current I_{off} flows. Thus, energy generated due to the current I_{off} is stored in the capacitor C and the battery **205**. As a result, the converted DC voltage is stored in the battery **205**.

As a result, the converted DC power is stored in the battery **205** by the on/off operation of the switching element S_1 , that is, the PWM operation.

The voltage boosting operation or the voltage drop operation of the driving unit **200**, that is, the charging apparatus **200**, may be determined by comparison between the voltage across the capacitor C and the voltage across the capacitor C_x provided at the output end of the rectifier **412**.

The controller **430** may control the duty ratio of the turn-on of the switching element S_1 so as to perform the voltage boosting operation if the voltage across the capacitor C_x is less than the voltage across the capacitor C . For example, it is possible to increase the duty ratio for voltage boost.

The controller **430** may control the duty ratio of the turn-on of the switching element S_1 so as to perform the voltage drop operation if the voltage across the capacitor C_x is greater than the voltage across the capacitor C . For example, it is possible to decrease the duty ratio for voltage drop.

FIG. **7** shows an example of the internal configuration of the controller of FIG. **3**.

Referring to FIG. **7**, the controller **430** may include an axis transformation unit **510**, a speed calculator **520**, a current command generator **530**, a voltage command generator **540**, an axis transformation unit **550** and a switching control signal output unit **560**.

The axis transformation unit **510** receives and transforms three-phase output currents i_a , i_b and i_c detected by the output current detector **E** into two-phase currents i_α and i_β of a stationary reference frame.

The axis transformation unit **510** may transform two-phase currents i_α and i_β of the stationary reference frame into two-phase currents i_d and i_q of a rotating reference frame.

The speed calculator **520** may calculate a speed $\hat{\omega}_r$ based on the location signal H of the rotator received from the position sensor **235**. That is, the speed calculator may calculate the speed by dividing the movement distance of the rotator by the time based on the location signal of the rotator.

The position sensor **235** may sense the location of the rotator of the motor **250**. The position sensor **235** may include a hall sensor.

The speed calculator **520** may output the calculated location $\hat{\theta}_r$ and the calculated speed $\hat{\omega}_r$ based on the received location signal H of the rotator.

The current command generator **530** calculates a speed command value ω_r^* based on the calculated speed $\hat{\omega}_r$ and a target speed ω_r and generates a current command value i_q^* based on the speed command value ω_r^* . For example, the current command generator **530** may perform PI control of the PI controller **535** based on the speed command value ω_r , which is the difference between the calculated speed $\hat{\omega}_r$ and the target speed ω_r and generate the current command value i_q^* . Although the q-axis current command value i_q^* is shown as the current command value in the figure, the d-axis current command value i_d^* may also be generated. In addition, the value of the d-axis current command value i_d^* may be set to 0.

The current command generator **530** may further include a limiter for limiting the level of the current command value i_q^* such that the current command value i_q^* does not exceed an allowable range.

Next, the voltage command generator **540** generates d-axis and q-axis voltage command values v_d^* and v_q^* based on d-axis and q-axis currents i_d and i_q transformed to the two-phase rotating reference frame by the axis transformation unit and the current command values i_d^* and i_q^* of the current command generator **530**. For example, the voltage command generator **540** may perform PI control of the PI controller **544** and generate the q-axis voltage command value v_q^* based on a difference between the q-axis current i_q and the q-axis current command value i_q^* . In addition, the voltage command generator **540** may perform PI control of the PI controller **548** and generate the d-axis voltage command value v_d^* based on a difference between the d-axis current i_d and the d-axis current command value i_d^* . The d-axis voltage command value v_d^* may be set to 0 if the d-axis current command value i_d^* is set to 0.

The voltage command generator **540** may further include a limiter for limiting the level of the d-axis and q-axis voltage command values v_d^* and v_q^* such that the d-axis and q-axis voltage command values v_d^* and v_q^* do not exceed an allowable range.

The generated d-axis and q-axis voltage command values v_d^* and v_q^* are input to the axis transformation unit **550**.

The axis transformation unit **550** receives the location $\hat{\theta}_r$, calculated by the speed calculator **520** and the d-axis and q-axis voltage command values v_d^* and v_q^* and performs axis transformation.

First, the axis transformation unit **550** transforms the two-phase rotating reference frame into the two-phase stationary reference frame. At this time, the location $\hat{\theta}_r$, calculated by the speed calculator **520** may be used.

The axis transformation unit **550** transforms the two-phase stationary reference frame into the three-phase stationary reference frame. Through such transformation, the axis transformation unit **550** outputs three-phase voltage command values v_a^* , v_b^* and v_c^* .

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The switching control signal output unit **560** generates and outputs an inverter switching control signal S_{ic} according to the pulse width modulation (PWM) method based on the three-phase output voltage command values v_a^* , v_b^* and v_c^* .

The output inverter switching control signal S_{ic} may be converted into a gate driving signal by a gate driving unit and may be input to the gates of the switching elements of the inverter **420**. Thus, the switching elements S_a , S'_a , S_b , S'_b , S_c and S'_c of the inverter **420** perform the switching operation.

The controller **430** may control the switching operation of the switching element S_1 of the switching unit **410**.

The charging apparatus and the electric vehicle including the same described throughout this disclosure are not restricted to the examples set forth herein. Therefore, variations and combinations of the examples set forth herein fall within the scope of the disclosure.

In some implementations, in the charging mode, the input AC voltage is converted into the DC voltage using the additional coil wound on the stator of any one phase of the motor, the switching unit, and the inverter, and is supplied to the battery. Accordingly, it may be possible to perform charging using the AC voltage.

In particular, when the charging apparatus operates in the charging mode, the switching element of the switching unit, the motor and the inverter operate in a flyback converter.

Since the charging apparatus operates as a flyback converter using only the additional coil and the switching element connected to the additional coil, it may be possible to reduce manufacturing costs.

In addition, in the charging mode, since all the switching elements of the inverter are turned off, the rotator of the motor does not move.

Since the inverter, the controller and the switching unit of the charging apparatus may be implemented on the same circuit board, it may be possible to implement a small-size charging apparatus.

The method for operating the charging apparatus may be implemented as code that is written to a processor-readable recording medium included in the charging apparatus and may thus be read by a processor. The processor-readable recording medium may be any type of recording device in which data can be stored in a processor-readable manner.

Although examples have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the disclosure and the accompanying claims.

What is claimed is:

1. A charging apparatus comprising:

a converter configured to, in a charging mode, receive an input alternating current (AC) voltage and convert the input AC voltage into an output direct current (DC) voltage; and

a controller configured to control the converter,

wherein the converter includes:

a motor that includes a stator and a rotator, and coils wound on the stator, the coils corresponding to different phases of the motor;

an additional coil wound on a portion of the stator that corresponds to a phase of the different phases of the motor;

a switching unit connected to the additional coil and configured to selectively supply the input AC voltage to the motor by performing a switching operation; and

an inverter configured to, in a motor operation mode, convert a battery DC voltage from a battery into an output AC voltage by performing a switching opera-

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tion of three-phase switching elements and drive the motor, and, in the charging mode, convert the input AC voltage into the output DC voltage using the additional coil of the motor and the switching unit and supply the output DC voltage to the battery.

2. The charging apparatus according to claim **1**, wherein, in the charging mode, a switching element of the switching unit, the motor, and the inverter operate as a flyback converter.

3. The charging apparatus according to claim **1**, wherein energy is stored in the additional coil by turning a switching element of the switching unit on and the stored energy is converted into the output DC voltage via the inverter and supplied to the battery by turning the switching element of the switching unit off.

4. The charging apparatus according to claim **1**, wherein, in the charging mode, the additional coil of the motor operates as a primary side of a transformer and a phase coil wound with the additional coil on the same portion of the stator, which corresponds to a phase of the different phases of the motor, operates as a secondary side of the transformer.

5. The charging apparatus according to claim **1**, wherein the controller is configured to, in the charging mode, control turning on and off of a switching element of the switching unit.

6. The charging apparatus according to claim **1**, wherein the inverter, the controller, and the converter are located on a same circuit board.

7. The charging apparatus according to claim **6**, wherein the controller is configured to, in the charging mode, turn off all of the three-phase switching elements of the inverter.

8. The charging apparatus according to claim **1**, wherein the converter includes a rectifier configured to rectify the input AC voltage and supply the rectified voltage to the motor.

9. The charging apparatus according to claim **1**, wherein the controller includes:

a speed calculator configured to calculate rotator speed information of the motor based on a location signal of the rotator of the motor;

a current command generator configured to generate a current command value based on the rotator speed information and a speed command value;

a voltage command generator configured to generate a voltage command value based on the current command value and a detected current flowing in the motor; and

a switching control signal output unit configured to output a switching control signal that drives the inverter based on the voltage command value.

10. The charging apparatus according to claim **1**, wherein the controller is configured to control a duty ratio of turning on the switching unit to perform a voltage boosting operation based on a first voltage across a first capacitor located between the motor and a rectifier of the converter being less than a second voltage across a second capacitor located between the inverter and the battery, and configured to control the duty ratio of turning on the switching unit to perform a voltage drop operation based on the first voltage across the first capacitor being greater than the second voltage across the second capacitor.

11. An electric vehicle comprising:

a battery; and

a charging apparatus including a converter configured to, in a charging mode, receive an input alternating current (AC) voltage and convert the input AC voltage into an output direct current (DC) voltage and a controller configured to control the converter,

wherein the converter includes:

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a motor that includes a stator and a rotator, and coils wound on the stator, the coils corresponding to different phases of the motor;

an additional coil wound on a portion of the stator that corresponds to a phase of the different phases of the motor;

a switching unit connected to the additional coil and configured to selectively supply the input AC voltage to the motor by performing a switching operation; and

an inverter configured to, in a motor operation mode, convert a battery DC voltage from a battery into an output AC voltage by performing a switching operation of three-phase switching elements and drive the motor, and, in the charging mode, convert the input AC voltage into the output DC voltage using the additional coil of the motor and the switching unit and supply the output DC voltage to the battery.

12. The electric vehicle according to claim 11, wherein, in the charging mode, a switching element of the switching unit, the motor, and the inverter operate as a flyback converter.

13. The electric vehicle according to claim 11, wherein the charging apparatus stores energy in the additional coil by turning a switching element of the switching unit on, and converts the stored energy into the output DC voltage via the inverter and supplies the converted DC voltage to the battery by turning the switching element of the switching unit off.

14. The electric vehicle according to claim 11, wherein, in the charging mode, the additional coil of the motor operates as a primary side of a transformer and a phase coil wound with the additional coil on the same portion of the stator, which corresponds to a phase of the different phases of the motor, operates as a secondary side of the transformer.

15. The electric vehicle according to claim 11, wherein the controller is configured to, in the charging mode, turn on and off all of the three-phase switching elements of the switching unit.

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16. The electric vehicle according to claim 11, wherein the inverter, the controller, and the switching unit are located on a same circuit board.

17. The electric vehicle according to claim 16, wherein the controller is configured to, in the charging mode, turn off all of the three-phase switching elements of the inverter.

18. The electric vehicle according to claim 11, wherein, the converter includes a rectifier configured to rectify the input AC voltage and supply the rectified voltage to the motor.

19. The electric vehicle according to claim 11, wherein the controller includes:

a speed calculator configured to calculate rotator speed information of the motor based on a location signal of the rotator of the motor;

a current command generator configured to generate a current command value based on the rotator speed information and a speed command value;

a voltage command generator configured to generate a voltage command value based on the current command value and a detected current flowing in the motor; and

a switching control signal output unit configured to output a switching control signal that drives the inverter based on the voltage command value.

20. The electric vehicle according to claim 11, wherein the controller is configured to control a duty ratio of turning on the switching unit to perform a voltage boosting operation based on a first voltage across a first capacitor located between the motor and a rectifier of the converter being less than a second voltage across a second capacitor located between the inverter and the battery, and configured to control the duty ratio of turning on the switching unit to perform a voltage drop operation based on the first voltage across the first capacitor being greater than the second voltage across the second capacitor.

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